AD-A060 283 NAVAL UNDERSEA CENTER SAN DIEGO CALIF F/G 17/1

COMPUTER GRAPHICS AND THE FINITE ELEMENT METHOD AS APPLIED TO S--ETC(U)

JUN 73 L E MCCLEARY, J T HUNT, R R SMITH

UNCLASSIFIED NUC-TN-1055 NL

1 OF 1

AD A060283

END

DATE FILMED

12-78

DDC

MOST Project = 4

NUC-TN-1055

LEVEL II

NAVAL UNDERSEA CENTER

COMPUTER GRAPHICS AND THE FINITE ELEMENT METHOD AS APPLIED TO SONAR TRANSDUCER ANALYSIS

by

L. E. McCleary, J. T. Hunt, R. R. Smith and D. Barach
Naval Undersea Center, San Diego, California

and

H. N. Christiansen
Brigham Young University, Provo, Utah
and University of Utah, Salt Lake City, Utah

F11121

Sponsored by PMS 302-42
Under Sub Project SF 11 121 304 Task 14062

SENSOR AND INFORMATION TECHNOLOGY DEPARTMENT

San Diego, California

6p.

June 1973

Approved for public release;
distribution unlimited.

390 458

COMPUTER GRAPHICS AND THE FINITE ELEMENT METHOD AS APPLIED TO SONAR TRANSDUCER ANALYSIS

L. E. McCleary, J. T. Hunt, R. R. Smith and D. Barach
Naval Undersea Center, San Diego, California

and

H. N. Christiansen
Brigham Young University, Provo, Utah
and University of Utah, Salt Lake City, Utah

Introduction

In order to adequately understand the vibratory characteristics of electromechanical sonar transducers, two sophisticated techniques, the finite element method and state-of-the-art computer graphics, have been successfully combined. This process has for the first time vividly demonstrated the normal mode behavior of a Navy sonar transducer.*

This paper briefly describes the actual transducer being analyzed as well as the method used, gives results for the first three constant voltage drive resonant frequencies, and shows now computer graphics plays a key role in any such endeavor.

Description of the Transducer

Figure 1 is a photograph of the transducer showing the following 5 main parts:

1. radiating head (a solid piece of titanium),
2. steel washer,
3. active ceramic piezoelectric tube,
4. tail mass (a solid piece of steel), and
5. steel stress rod.

This electromechanical transducer is one element in a sonar array containing several hundred of these devices. When each element is driven electrically it produces a mechanical motion in the head which in turn is the source for an acoustic pressure wave in the water. Since the behavior of the entire array is of critical importance to the Navy, it is obvious that the response from individual elements must be thoroughly understood so that the interactions between many such devices, which are arranged in a geometrical physical array, can be predicted.

*This work has been sponsored by the Naval Ship Systems Command, PMS 302-42 under SF 11 121 304, Task 14062.

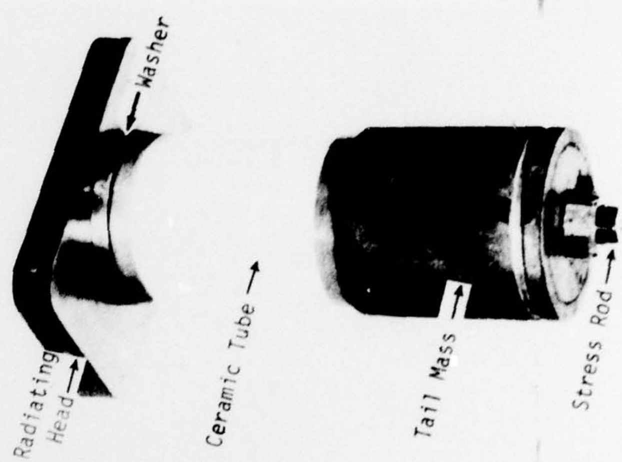

FIG. 1 Actual Transducer

Overview of the Finite Method

In order to calculate the displacement distribution within the entire transducer, the eigenvalue equation $(-\omega^2 M + K) U = 0$ is solved for its eigenfrequencies ω_i, and the corresponding eigenvectors U_i, which are the normal modes. The generation of the composite consistent mass matrix M and the composite stiffness matrix K is discussed in the following paragraphs. In order to solve the entire problem it is necessary to have a finite element computer program and to proceed as follows:

1. Construct a finite element idealization of the structure. This involves decomposing the entire body into small elements such as rods, beams, plates, or various solid elements, each of which is hopefully available as a routine in the computer program. This requires first of all that coordinate data and any other pertinent data must be prepared for the nodes of each of the elements of the idealization. Additional information provides the nodal connection order for each element. These element routines then

create individual mass and stiffness matrices where, for example, the stiffness matrix may relate displacements at each of the nodal points to forces at the nodal points. The order of each matrix generated here is the product of the number of nodes in the element and the number of degrees of freedom, where the number of degrees of freedom at each node is the number of undetermined field variables at that node.

2. Assemble the individual element matrices, given their geometrical relationships to each other, into the composite mass matrix M, and the composite stiffness matrix K. This is done automatically in the program by recognizing which elements have nodes in common and overlaying the individual element matrices into what becomes the composite or total matrices M and K.

3. Apply desired boundary conditions and solve the eigenvector/eigenvalue problem where the matrices are usually large, semi-positive definite, and banded.

4. Try to figure out what the hundreds or thousands of numbers generated by the computer mean.

Transducer Analysis Using the Finite Element Method

The vibratory characteristics of a particular electromechanical sonar transducer have been calculated under a joint project between the Transducer and Array Systems Division of the Naval Undersea Center, San Diego and the General Dynamics /Electric Boat Division, Sonar Development Program. The finite element computer program used is called MARTSAM, a generalized finite element program developed for Navy usage by GD/EB. This program is especially well suited for sonar transducer analysis due to its extensive library of routines for handling solid elements and fluid elements.

The various components were modeled in the program as follows:

1. The head, washer, and tail mass were idealized using HEX20 elements. This MARTSAM element is a hexahedron composed of 20 nodal points. The three nodal points along each edge of the hexahedron permits quadratic interpolation of both the geometry and the generalized displacement field along this line. Each nodal point has 3 degrees of freedom, i.e., a vector value displacement in the x, y, and z direction.

2. The active ceramic piezoelectric tube was idealized using PHEX20 elements which are identical to the HEX20 elements except that at each node there is one more degree of freedom, the electrical potential. This additional degree of freedom permits one to model the piezoelectric effect.

3. The stress rod was mathematically modeled using rod elements. Each of these elements has 3 nodes, between which a one-dimensional displacement function is quadratically interpolated.

By exploiting the geometrical symmetry of the entire transducer, the finite element mathematical model need only include an idealization for 1/4 of the device, resulting in 1135 degrees of freedom. Deformation of the entire transducer is represented by nearly 4000 numbers.

Excellent agreement between the computed results and experiment were achieved. This agreement is demonstrated vividly by taking computer generated contour plots of the mode shapes and comparing them with experimentally measured deformations obtained by holographic interferometry.[1]

Computer Graphics in Conjunction With the Finite Element Method

Computer graphics plays three vital roles in the example being described: (1) experiment is compared with theory using computer generated contour plots; (2) before the problem has been solved on the computer the raw coordinate data is plotted to verify that the finite element idealization does in fact represent the actual device; and finally, (3) three dimensional displays of the various deformations of the device are produced.

Three distinct methods will be discussed for plotting three dimensional perspective views of the device with or without deformation. They are the following:

1. Line drawings with no hidden lines removed,
2. Line drawings with hidden lines removed, and
3. Continuous tone shaded pictures.

Method 1, shown in Figure 2, is the easiest and least expensive to obtain. Although this method has obvious deficiencies, it can be used profitably for rough data checking. Figure 3 demonstrates the type of error which can easily be spotted and corrected using this technique. In this case only one surface at a time is displayed in order to eliminate the clutter created by several surfaces. For many applications involving complicated solid elements having many input nodal points, it is frequently useful to draw the elements as 3-D line drawings using single-headed arrows to trace the order in which the points are input as a further check on the data.

Method 2 is shown in Figure 4. Here we see the data generated again as a line drawing but with the hidden lines removed. The software algorithm required to suppress

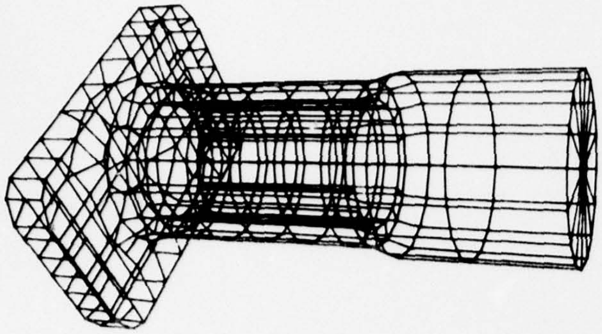

FIG. 2. Line Drawing Without Hidden Line Suppression

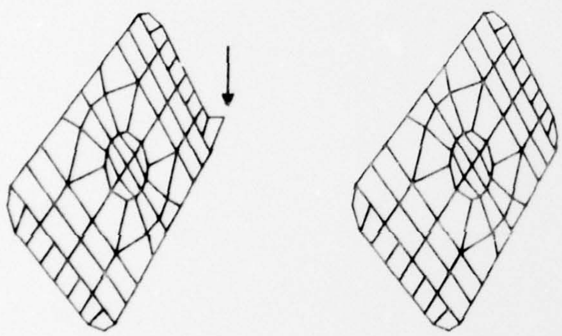

FIG. 3. Line Drawings of One Surface With and Without Erroneous Data

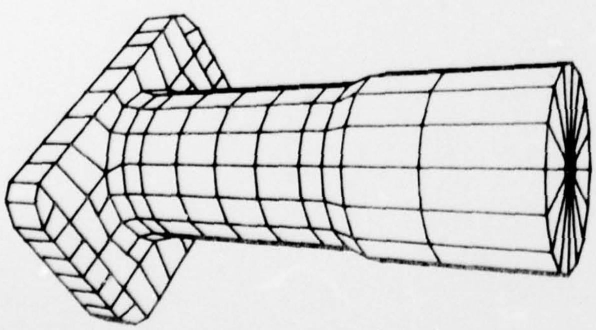

FIG. 4. Line Drawing with Hidden Lines Removed

the hidden lines requires more computer time than Method 1, but the final product is far more useful and easier to understand.

Method 3 demonstrates the most sophisticated and effective method for displaying the data. Figures 5-14 have been produced by the University of Utah computer graphics system which has been under development for several years.[2] These continuous tone pictures are produced on a raster driven cathode ray tube which has 1024 dots on each of 1024 lines. A camera is mounted in front of the screen so that for each desired picture the camera shutter remains open as each line is drawn. Therefore the final picture is an integration of all the lines drawn on the tube. A significant breakthrough in the time required to produce each of these pictures was achieved in 1972 when the Watkins processor became operational. This device provides a hardware solution to the hidden surface and shading problem so that now the time required for this portion of the picture production is negligible. Two types of shading are available. One, which we call "unsmoothed", produces a flat look for each of the surface elements. The other is called "smoothed" shading which can be used to simulate curved surfaces very nicely, provided there are enough elements over the curved surface.

To clarify Method 3 and to show the three resonant frequencies from the analysis, the following figures are described:

1. Figure 5 is the entire undeformed transducer (not including the stress rod in the display) shown in an unsmoothed mode.

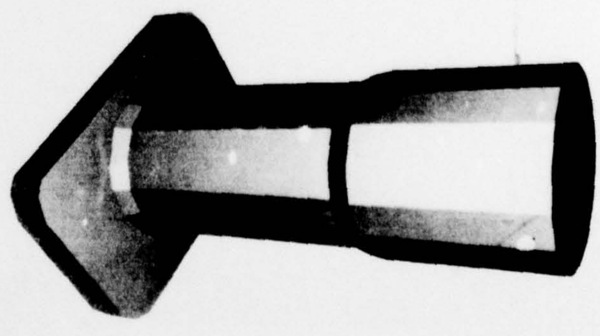

FIG. 5. Undeformed Transducer(Unsmoothed)

2. Figure 6 is the same as Figure 5 except that an additional feature of the graphic capability is shown, namely, that of exploding the device into separate components for viewing purposes.

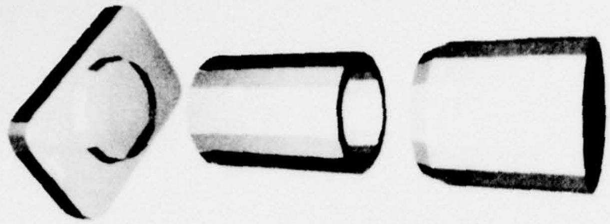

FIG. 6. Exploded View of Transducer Components (Unsmoothed)

3. Figure 7 is a smoothed version of just the ceramic tube from Figure 6.

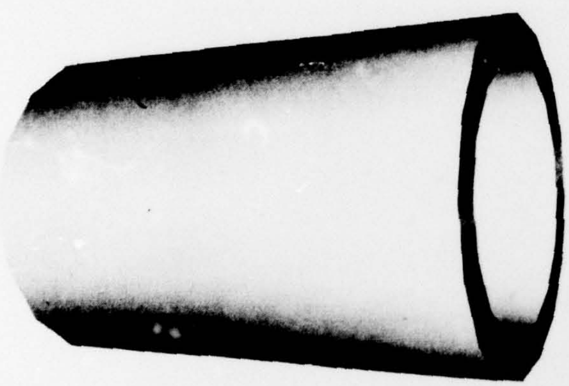

FIG. 7. Ceramic Tube (Smoothed)

4. Figure 8 shows the same device as Figure 5 except that it is now smoothed.

5. Figure 9 is an unsmoothed display of the device in its first normal mode.

6. Figure 10 is a smoothed display of Figure 9 at a different viewpoint.

7. Figure 11 is an unsmoothed display of the device in its second normal mode.

8. Figure 12 is a smoothed version of Figure 11.

9. Figure 13 is an unsmoothed display of the third normal mode of the device.

10. Figure 14 is a smoothed version of Figure 13 from a different viewpoint.

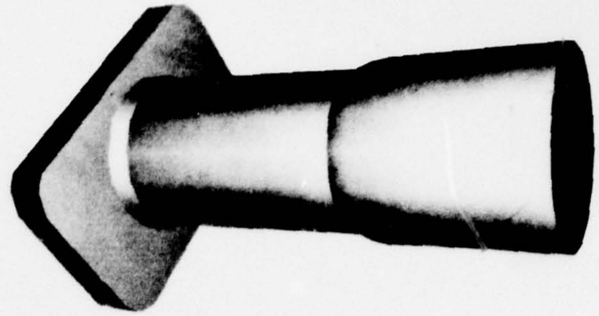

FIG. 8. Undeformed Transducer (Smoothed)

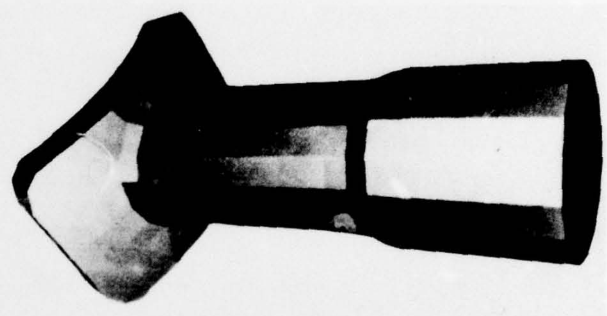

FIG. 9. First Normal Mode (Unsmoothed)

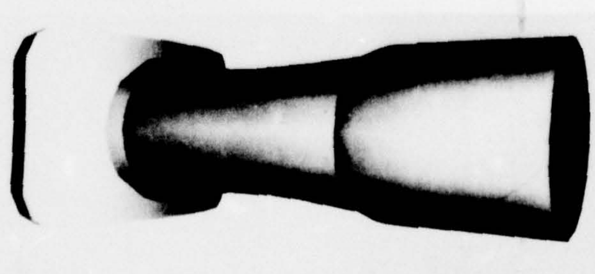

FIG. 10. First Normal Mode (Smoothed)

FIG. 11. Second Normal Mode (Unsmoothed)

FIG. 12. Second Normal Mode (Smoothed)

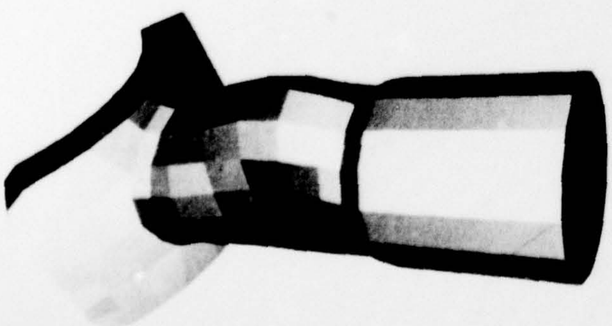

FIG. 13. Third Normal Mode (Unsmoothed)

FIG. 14. Third Normal Mode (Smoothed)

Another feature of the system not demonstrated in this paper is the ability to display color images. The color is produced by inserting primary color filters one at a time over the camera lens and generating lines at various intensities to achieve the desired color in the final picture. This leads to applications where objects can be displayed in three dimensions with a fourth variable (represented by color) superimposed upon the surface.

One further step will be taken with the results shown in this report. A movie of the motion of the transducer in the time domain at each of the three normal modes will be generated. This is expected to be ready for the conference in August 1973.

Conclusion

Finite element analysis, which has contributed significantly to the understanding of the vibratory characteristics of sonar transducers, has been greatly enhanced by the use of sophisticated computer graphics as an aid in interpreting very large calculations.

References

1. J. T. Hunt, R. R. Smith, D. Barach, L. McCleary, Naval Undersea Center, and C. Johnson, Naval Underwater Systems Center, "Applications of the Finite Element Method and Computer Graphics, A Vibrational Analysis of A Sonar Projector Transducer Element", NUC TP 321 of December 1972.

2. H. N. Christiansen, "Computer Generated Displays of Structures in Vibration", preprint presented at AIAA/ASME/SAE 14th Structures, Structural Dynamics and Materials Conference, Williamsburg, Va., March 21, 1973.